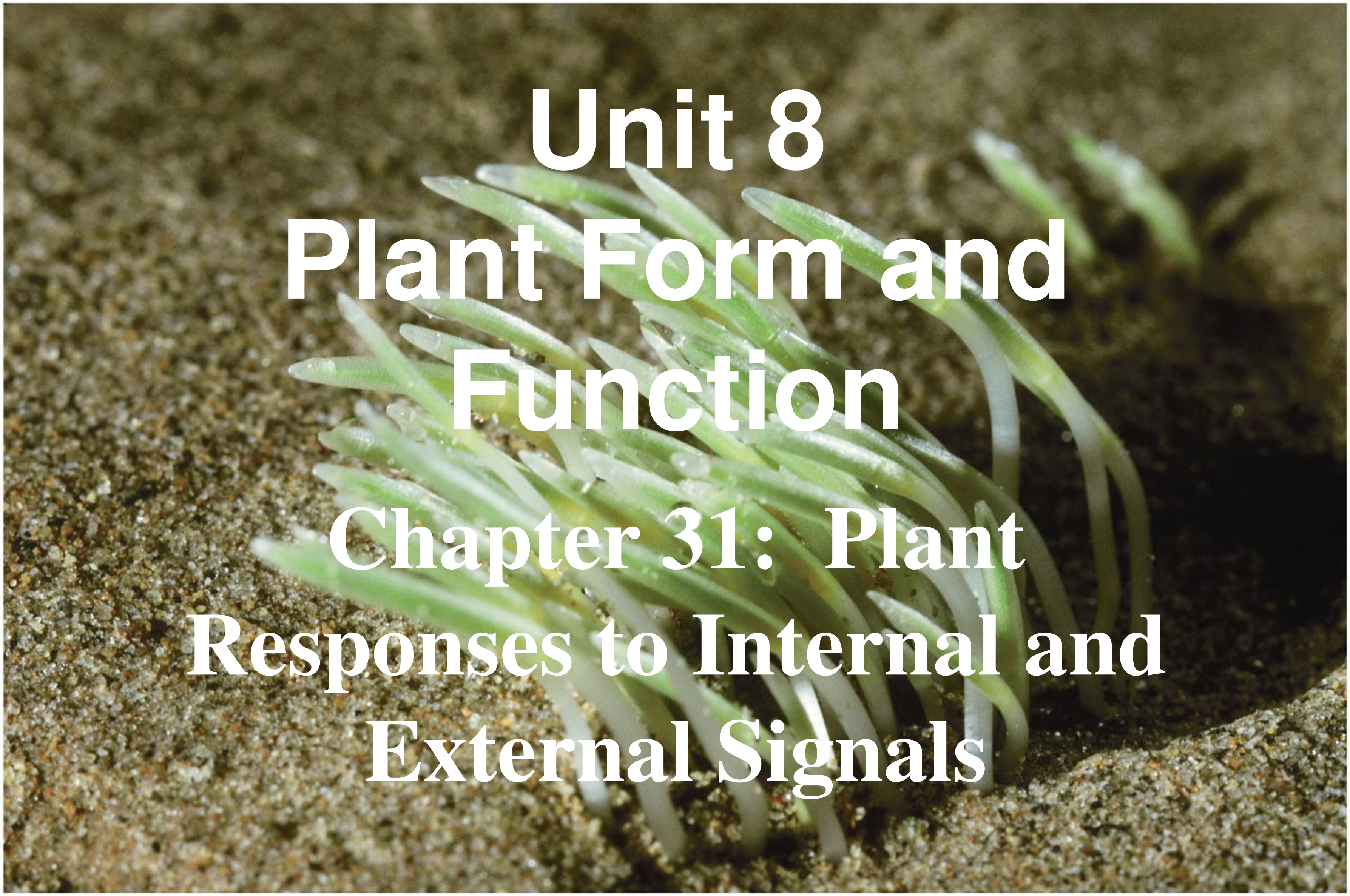


Unit 8
Plant Form and Function

Chapter 31: Plant Responses to Internal and External Signals

Overview: The Race to Live

- Young seedlings must outcompete their neighbors in the race for resources in order to survive
- Unlike animals, which respond through movement, plants must respond to environmental challenges by altering their growth and development

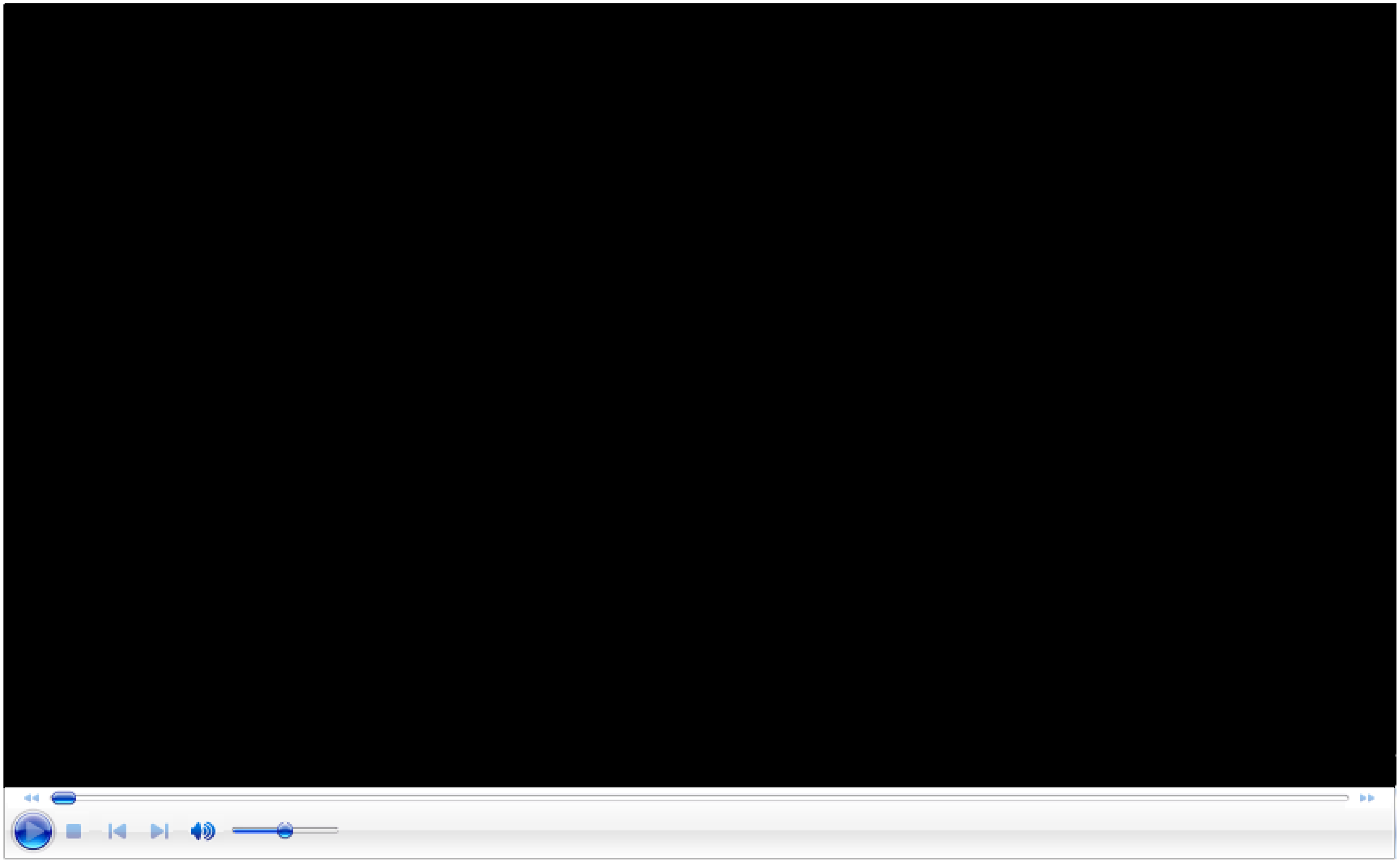
Concept 31.1: Plant hormones help coordinate growth, development, and responses to stimuli

- Plant **hormones** are chemical signals that modify or control one or more specific physiological processes within a plant
- Plant hormones are produced in very low concentration, but a minute amount can greatly affect growth and development of a plant organ
- Each hormone has multiple effects
- Multiple hormones can influence a single process
- Most aspects of plant growth and development are under hormonal control
  - Interactions between different hormones

The Discovery of Plant Hormones

- Any response resulting in curvature of organs toward or away from a stimulus is called a **tropism**
- The growth of a plant toward or away from light is called **phototropism**
  - Roots exhibit negative phototropism
  - Shoots exhibit positive phototropism
    - Directs shoot growth toward sunlight for photosynthesis
    - Cells on the darker side elongate faster than cells on the brighter side

- In the late 1800s, Charles Darwin and his son Francis conducted experiments on phototropism
- They observed that a grass seedling could bend toward light only if the tip of the coleoptile was present
  - They postulated that a signal was transmitted from the tip to the elongating region
- In 1913, Peter Boysen-Jensen demonstrated that the signal was a mobile chemical substance
- In 1926, Frits Went extracted the chemical messenger for phototropism, auxin, by modifying earlier experiments



Video: Phototropism

Figure 31.2

Results

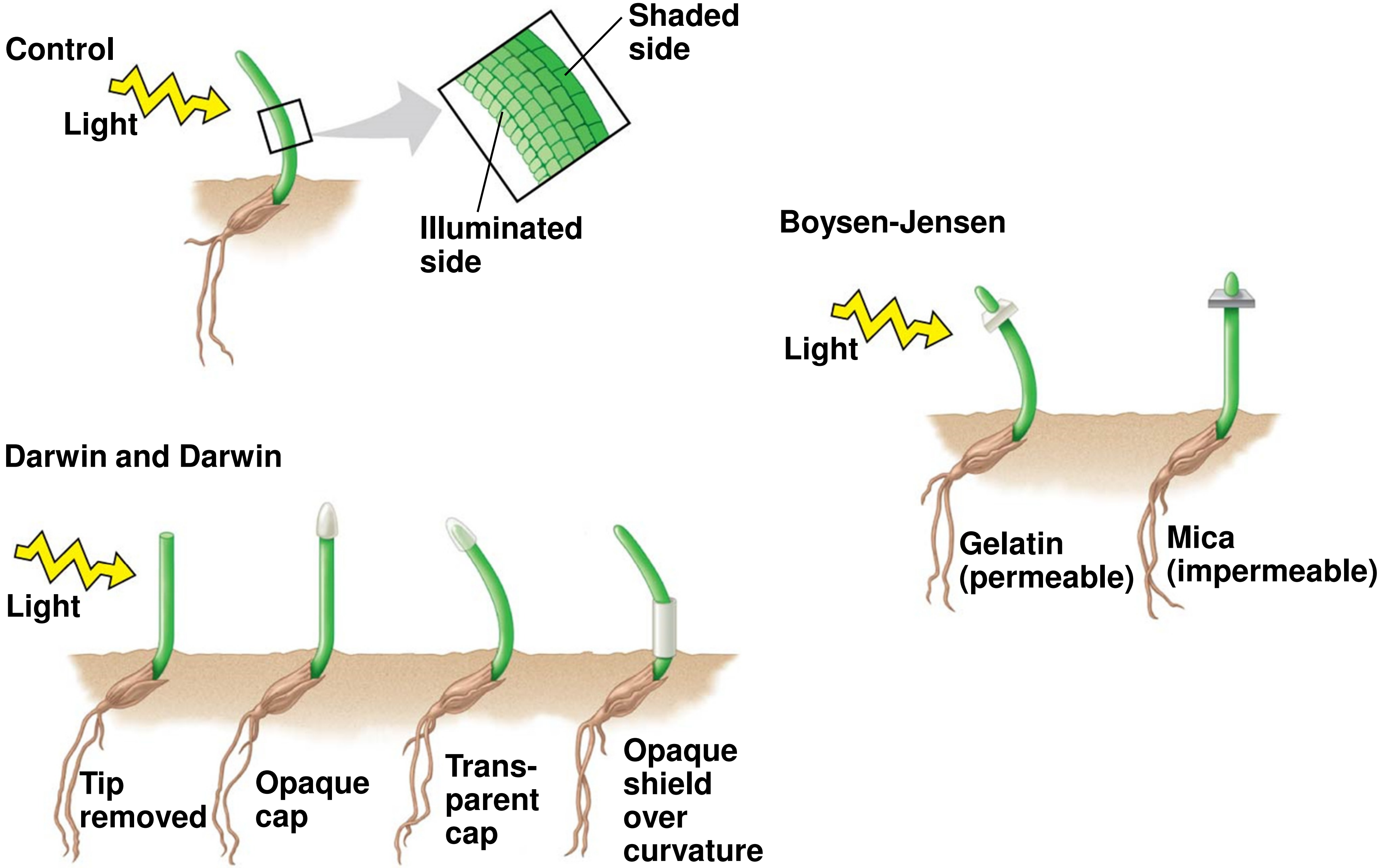
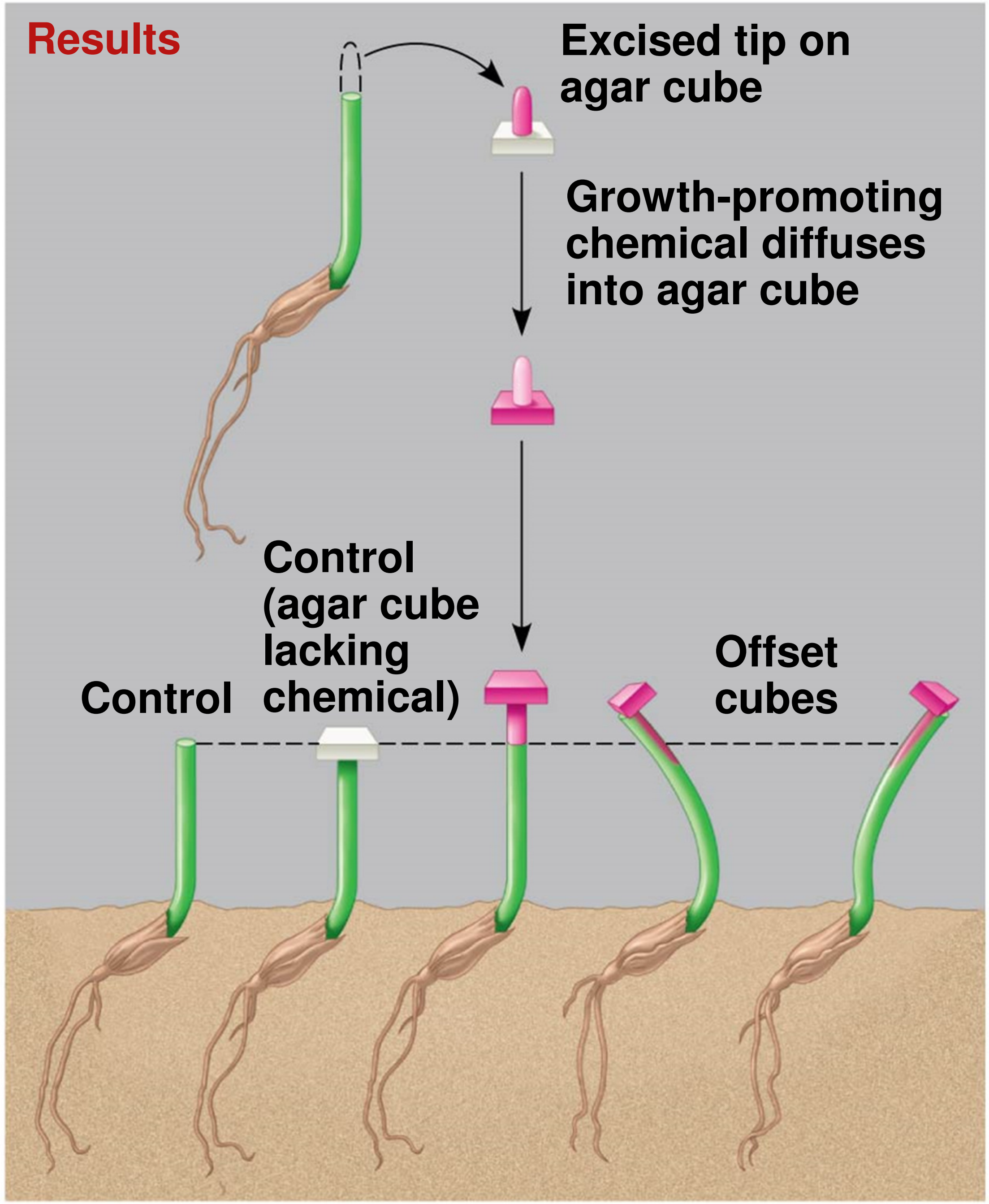


Figure 31.3


Results
Excised tip on agar cube
Growth-promoting chemical diffuses into agar cube
Control
Control (agar cube lacking chemical)
Offset cubes

A Survey of Plant Hormones

- The major classes of plant hormones include
  - Auxin
  - Cytokinins
  - Gibberellins
  - Brassinosteroids
  - Abscisic acid
  - Ethylene

Auxin

- The term **auxin** refers to any chemical that promotes elongation of coleoptiles
- Auxin is produced in shoot tips and is transported down the stem
  - The apical bud is the primary source of auxin
- Auxin also alters gene expression and stimulates a sustained growth response

- Auxin also play a role in plant development
  - Polar transport of auxin controls the spatial organization of the developing plant
  - Reduced auxin flow from the shoot of a branch stimulates growth in lower branches
  - Auxin transport plays a role in phyllotaxy
    - Arrangement of leaves on the stem
- If the apical bud is removed, the inhibition of axillary buds is removed
  - Plant becomes bushier

- Practical uses for auxins
  - Stimulates adventitious roots and is used in vegetative propagation of plants by cuttings
  - An overdose of synthetic auxins can kill plants
    - For example 2,4-D is used as an herbicide on eudicots
  - Tomato growers spray their plants with synthetic auxins to stimulate fruit growth

Cytokinins

- **Cytokinins** are so named because they stimulate cytokinesis (cell division)
  - Work together with auxin to control cell division and differentiation
  - Produced in actively growing tissues such as roots, embryos, and fruits
- Cytokinins also slow the aging of some plant organs

Gibberellins

- **Gibberellins** (GAs) have a variety of effects
  - Stem elongation
    - Stimulate stem and leaf growth by enhancing stem elongation AND cell division
  - Fruit growth
    - In many plants, both auxin and gibberellins must be present for fruit to develop
  - Seed germination
    - Release of gibberellins from the embryo signals seeds to break dormancy and germinate
- Gibberellins are produced in young roots and leaves

Figure 31.6

(a) Rosette form (left) and gibberellin-induced bolting (right)

(b) Grapes from control vine (left) and gibberellin-treated vine (right)

Brassinosteroids

- **Brassinosteroids** are chemically similar to cholesterol and the sex hormones of animals
  - Induce cell elongation and division in stem segments and seedlings
  - Slow leaf abscission (leaf drop)
  - Promote xylem differentiation

Abscisic Acid

- **Abscisic acid (ABA)** slows growth
- Two of the many effects of ABA include
  - Seed dormancy
    - Ensures that the seed will germinate only in optimal conditions
  - Drought tolerance
    - ABA accumulation causes stomata to close rapidly

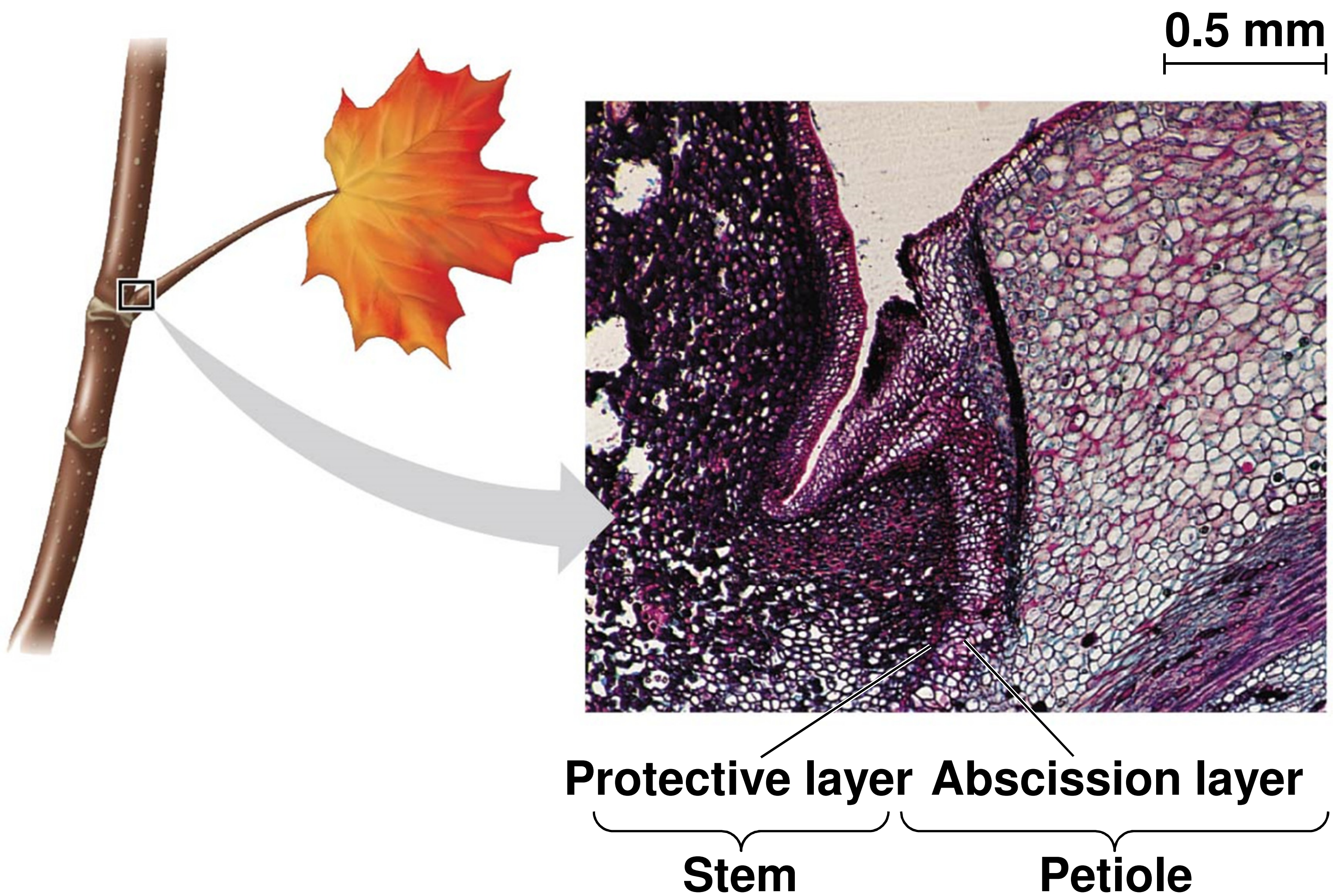
Ethylene

- Plants produce **ethylene** in response to stresses such as drought, flooding, mechanical pressure, injury, and infection
- The effects of ethylene include
  - Response to mechanical stress
  - Senescence
  - Leaf abscission
  - Fruit ripening

- Ethylene induces the **triple response**, which allows a growing shoot to avoid obstacles
- The triple response consists of
  - A slowing of stem elongation
  - A thickening of the stem
  - Horizontal growth

- **Senescence** is the programmed death of cells or organs
  - A burst of ethylene is associated with apoptosis, the programmed destruction of cells, organs, or whole plants
- A change in the balance of auxin and ethylene controls leaf abscission
  - The process that occurs in autumn when a leaf falls
  - Helps prevent desiccation during seasons when water is not as available to roots

Figure 31.10



- A burst of ethylene production in a fruit triggers the ripening process
  - Ethylene triggers ripening, and ripening triggers release of more ethylene
  - Ethylene is a gas and spreads from fruit to fruit
- Fruit producers can control ripening by picking green fruit and controlling ethylene levels

Concept 31.2: Responses to light are critical for plant success

- Light triggers many key events in plant growth and development, collectively known as **photomorphogenesis**
- Light reception also allows plants to measure the passage of days and seasons

Photomorphogenesis

- Morphological adaptations for growing in darkness are called **etiolation**
  - Ex: Young potato
- After exposure to light, a potato undergoes changes called **de-etiolation**, in which shoots and roots grow normally
  - "Greening"

Figure 31.11

(a) Before exposure to light

(b) After a week's exposure to natural daylight

- Plants detect not only presence of light but also its direction, intensity, and wavelength (color)
- A graph called an **action spectrum** depicts relative response of a process to different wavelengths
- Action spectra are useful in studying any process that depends on light
  - Reveal that red and blue light are the most important colors in photomorphogenesis

- Different plant responses can be mediated by the same or different photoreceptors
- There are two major classes of light receptors:
  - **Blue-light photoreceptors**
  - **Phytochromes**
    - Photoreceptors that absorb mostly red light

Blue-Light Photoreceptors

- Blue light initiates
  - Phototropism (movement in response to light)
  - Stomatal opening

Phytochrome Photoreceptors

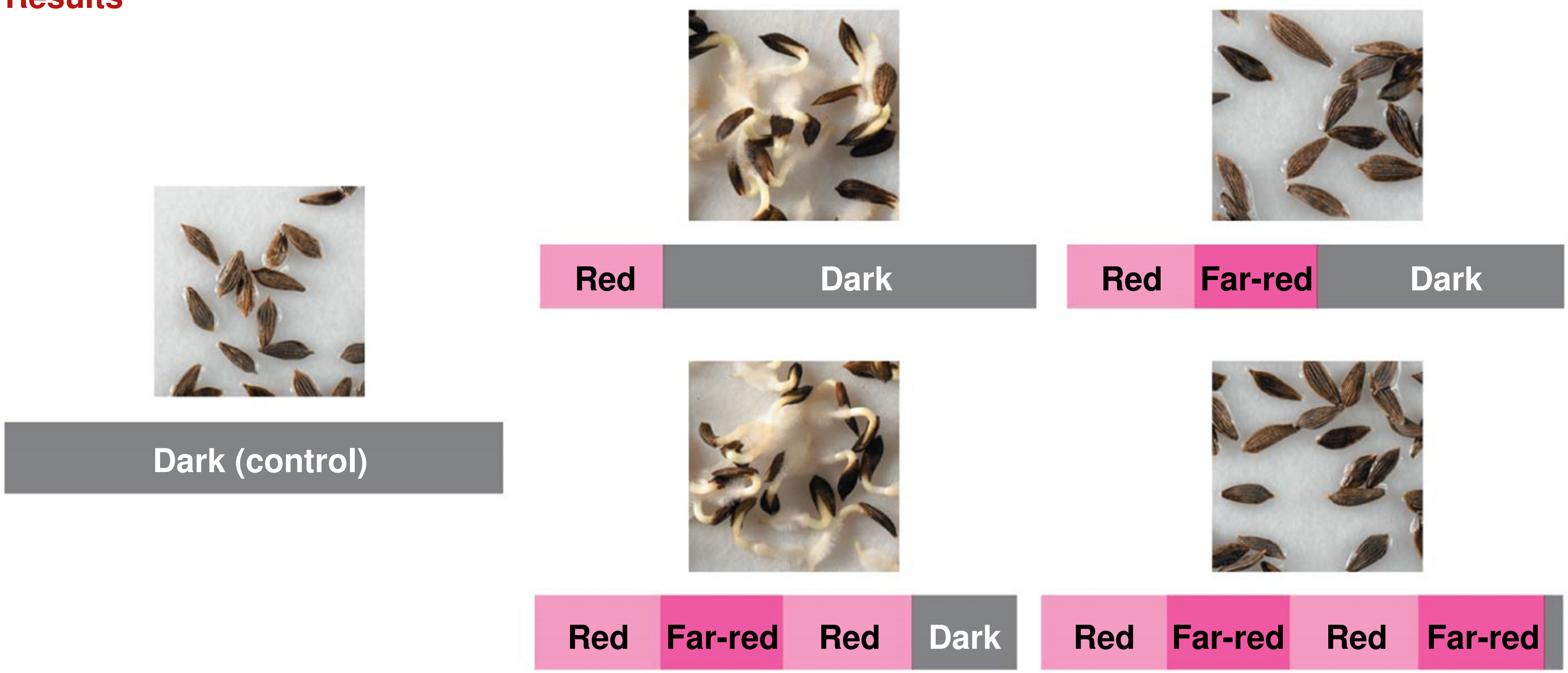
- Phytochromes are pigments that regulate many of a plant's responses to light throughout its life
- These responses include
  - Seed germination
  - Shade avoidance

Phytochromes and seed germination

- Many seeds remain dormant until light conditions are optimal
- The photoreceptor responsible for the opposing effects of red and far-red light is a phytochrome
  - Red light increased germination
  - Far-red light inhibited germination
  - The final light exposure is the determining factor
    - The effects of red and far-red light are reversible

Figure 31.13

Results



Phytochromes and shade avoidance

- The phytochrome system also provides the plant with information about the quality of light
  - Leaves in the canopy absorb red light
  - Shaded plants receive more far-red than red light
  - In the “shade avoidance” response, the phytochrome absorbs more red light when a tree is shaded
- This shift induces the vertical growth of the plant

Biological Clocks and Circadian Rhythms

- Many plant processes oscillate during the day
- Many legumes lower their leaves in the evening and raise them in the morning, even when kept under constant light or dark conditions
- **Circadian rhythms** are cycles that are about 24 hours long and are governed by an internal "clock"
  - The clock may depend on synthesis of a protein regulated through feedback control
- The factor that entrains the biological clock to precisely 24 hours every day is light
- Phytochrome conversion marks sunrise and sunset, providing the biological clock with environmental cues

Figure 31.15

Noon **10:00 PM**

Photoperiodism and Responses to Seasons

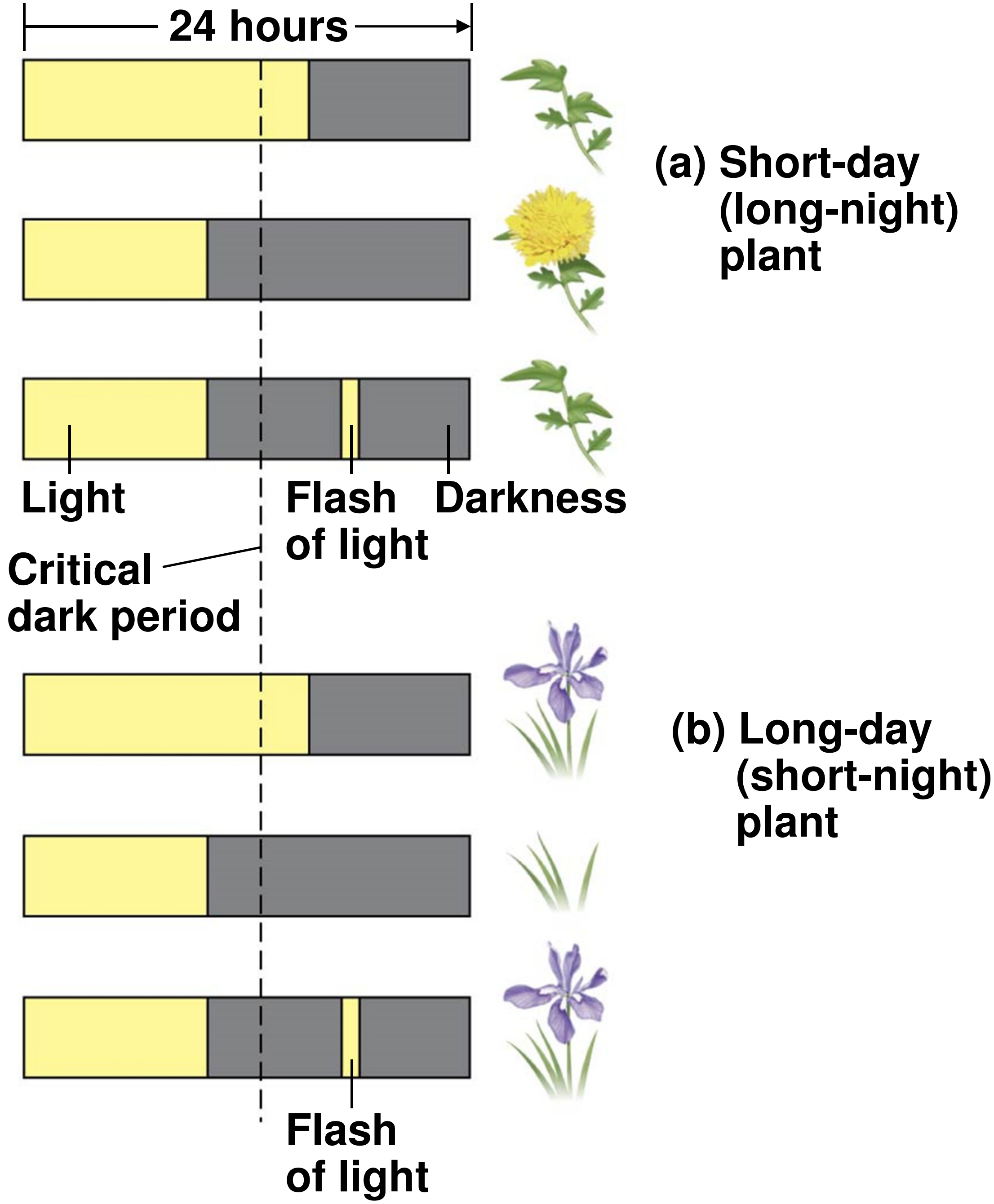
- Seed germination, flowering, and onset and breaking of bud dormancy are all stages that usually occur at specific times of the year
- Photoperiod, the relative lengths of night and day, is the environmental stimulus plants use most often to detect the time of year
- **Photoperiodism** is a physiological response to photoperiod
  - Ex: Flowering

Photoperiodism and Control of Flowering

- Some processes, including flowering in many species, require a certain photoperiod
- Plants that flower when a light period is shorter than a critical length are called **short-day plants**
  - Chrysanthemums, pointsettias
- Plants that flower when a light period is longer than a certain number of hours are called **long-day plants**
  - Spinach, radishes, lettuce, irises
- Flowering in **day-neutral plants** is controlled by plant maturity, not photoperiod
  - Tomatoes, rice, dandelions

- Researchers discovered that flowering and other responses to photoperiod are actually controlled by <u>night length</u>, not day length
  - Short-day plants are really long-night plants
    - Governed by whether the critical night length sets a minimum number of hours of darkness
  - Long-day plants are really short-night plants
    - Governed by whether the critical night length sets a maximum number of hours of darkness

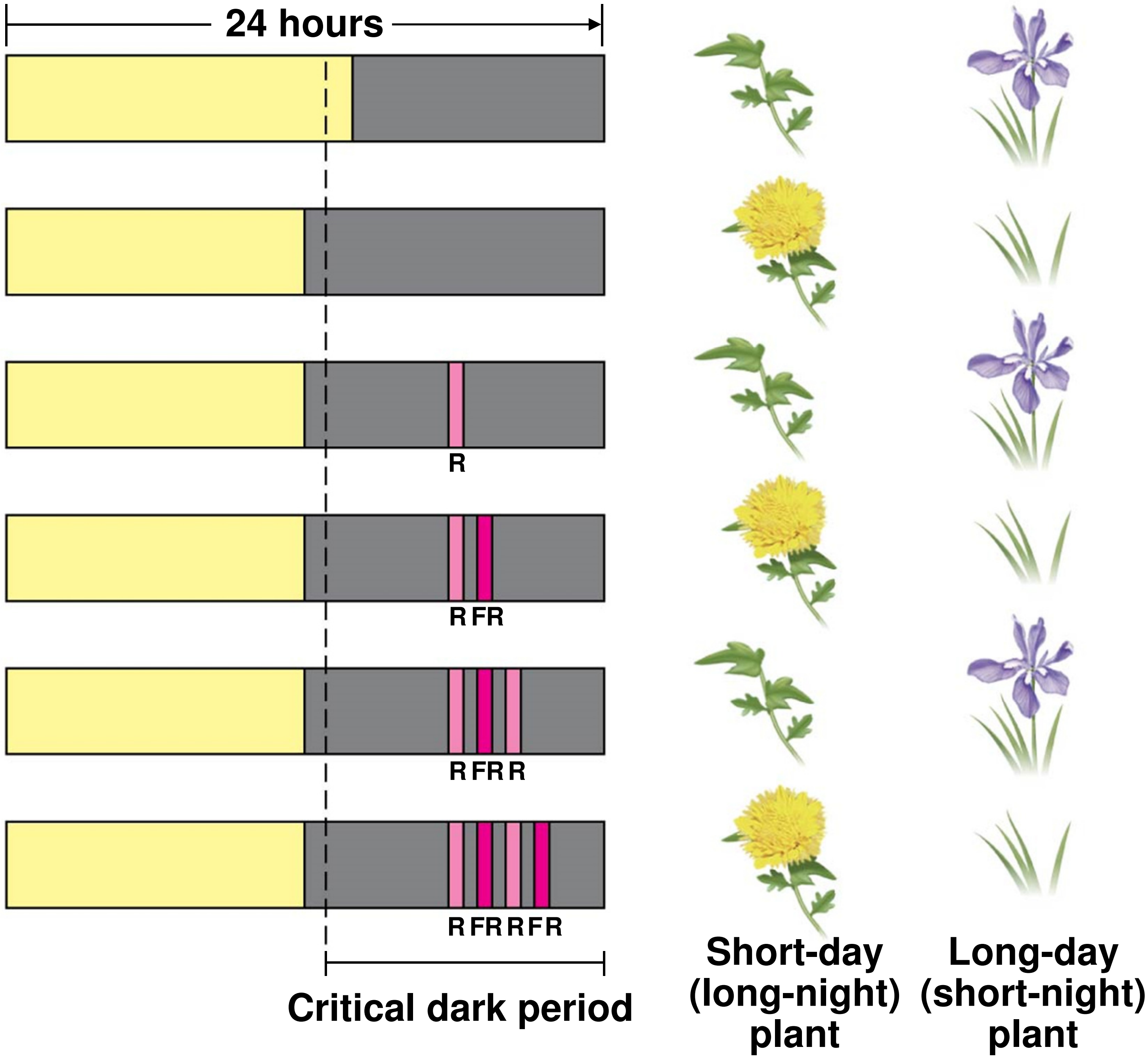
Figure 31.16



24 hours
Light
Flash of light
Darkness
Critical dark period
(a) Short-day (long-night) plant
(b) Long-day (short-night) plant
Flash of light

- Red light can interrupt the nighttime portion of the photoperiod
- A flash of red light followed by a flash of far-red light does not disrupt night length
- Action spectra and photoreversibility experiments show that phytochrome is the pigment that receives red light
- This knowledge is applied to produce flowers out of season

Figure 31.17



24 hours
R
R FR
R FR R
R FR R FR
Critical dark period
Short-day (long-night) plant
Long-day (short-night) plant

- Some plants flower after only a single exposure to the required photoperiod
- Other plants need several successive days of the required photoperiod
- Still others need an environmental stimulus in addition to the required photoperiod
  - For example, **vernalization** is a pretreatment with cold to induce flowering

A Flowering Hormone?

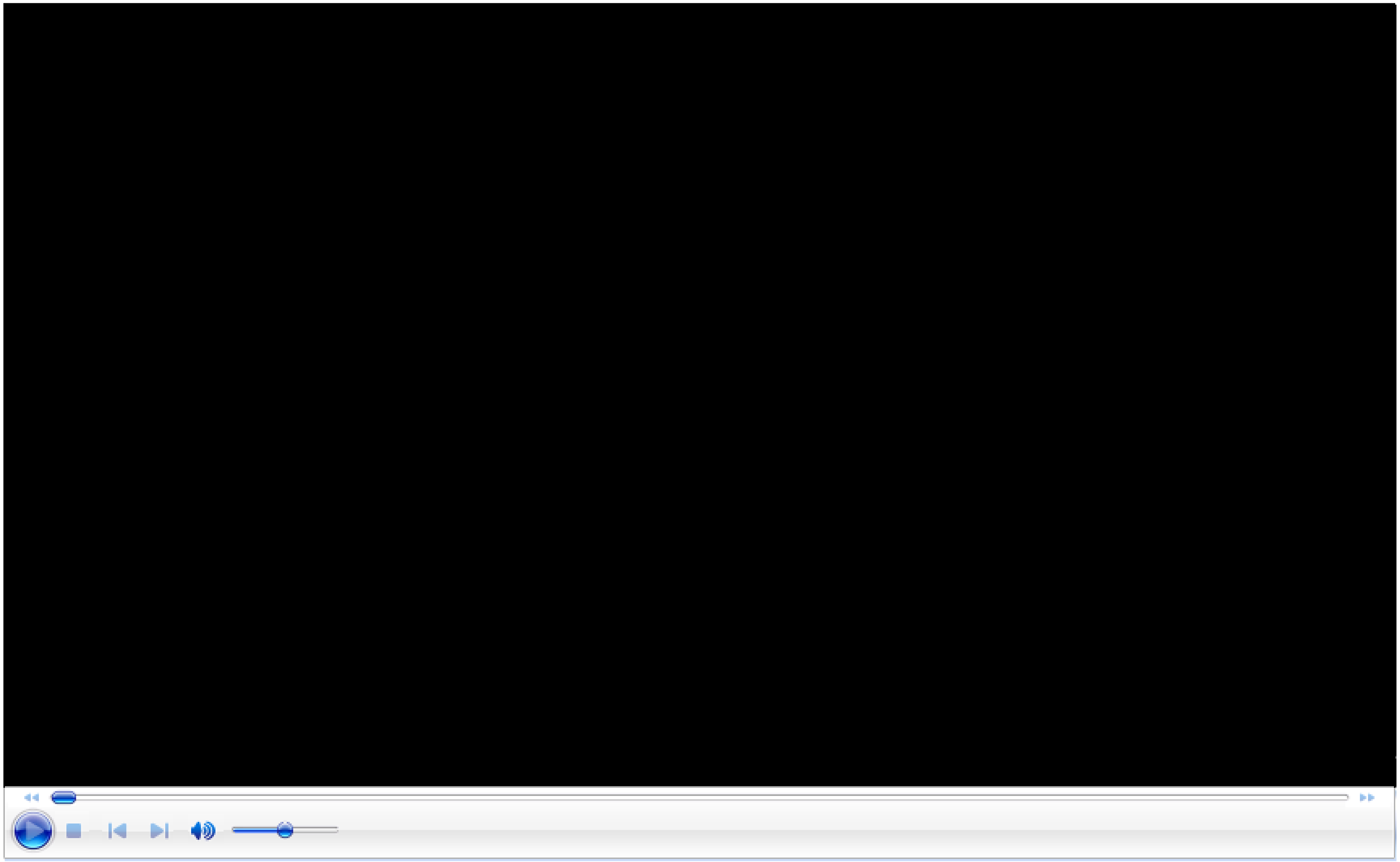
- Photoperiod is detected by leaves, which cue buds to develop as flowers
  - If all the leaves are removed, the plant is insensitive to photoperiod
- The flowering signal is called **florigen**

Concept 31.3: Plants respond to a wide variety of stimuli other than light

- Because of immobility, plants must adjust to a range of environmental circumstances through developmental and physiological mechanisms

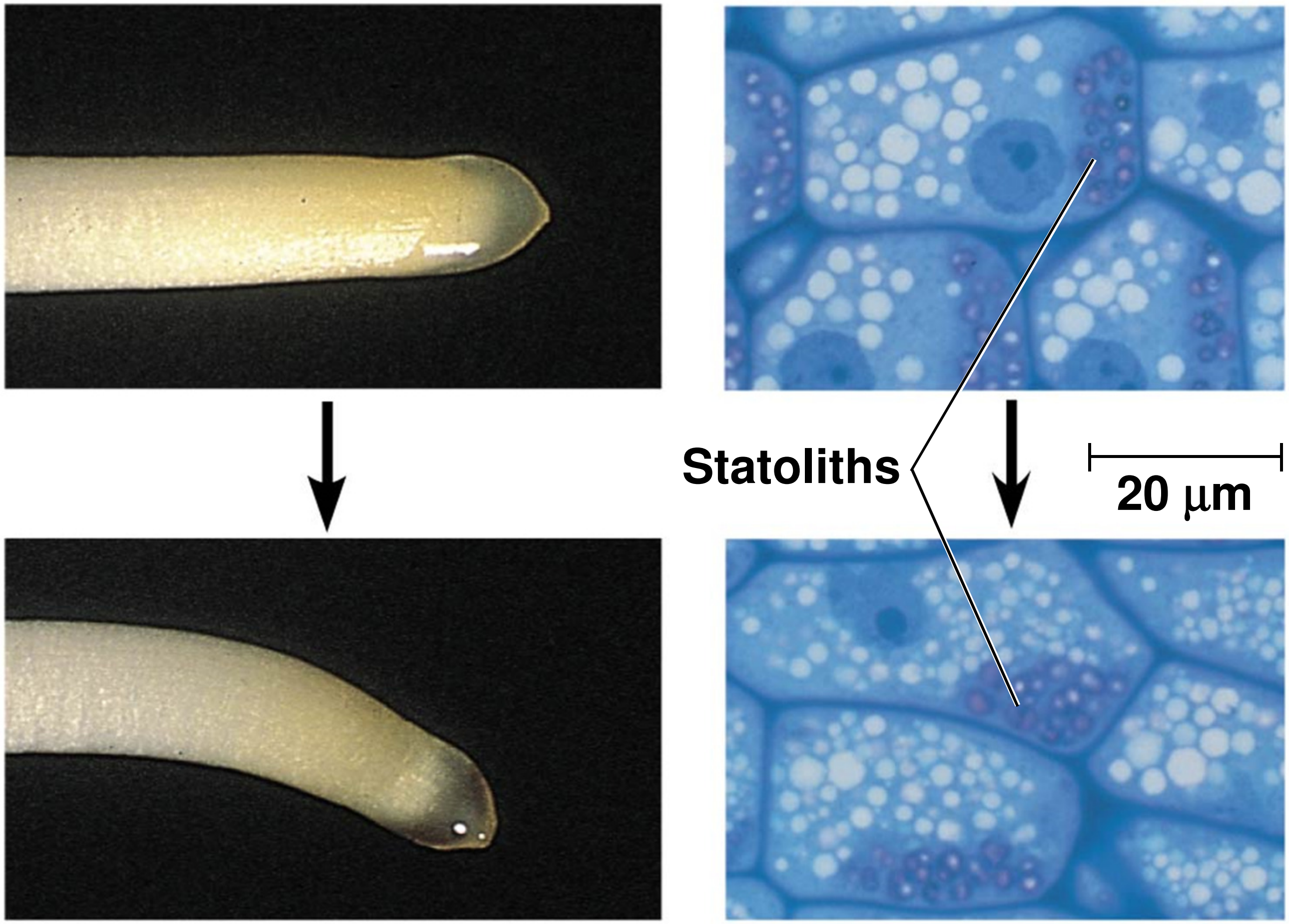
Gravity

- Response to gravity is known as **gravitropism**
  - Roots show positive gravitropism by growing downward
  - Shoots show negative gravitropism by growing upward
- Ensures roots grow into soil and shoot grows toward light, regardless of how the seed is oriented when it lands
- Plants may detect gravity by the settling of **statoliths**
  - Dense cytoplasmic components that settle under the influence of gravity to lower portions of cell



Video: Gravitropism

Figure 31.19



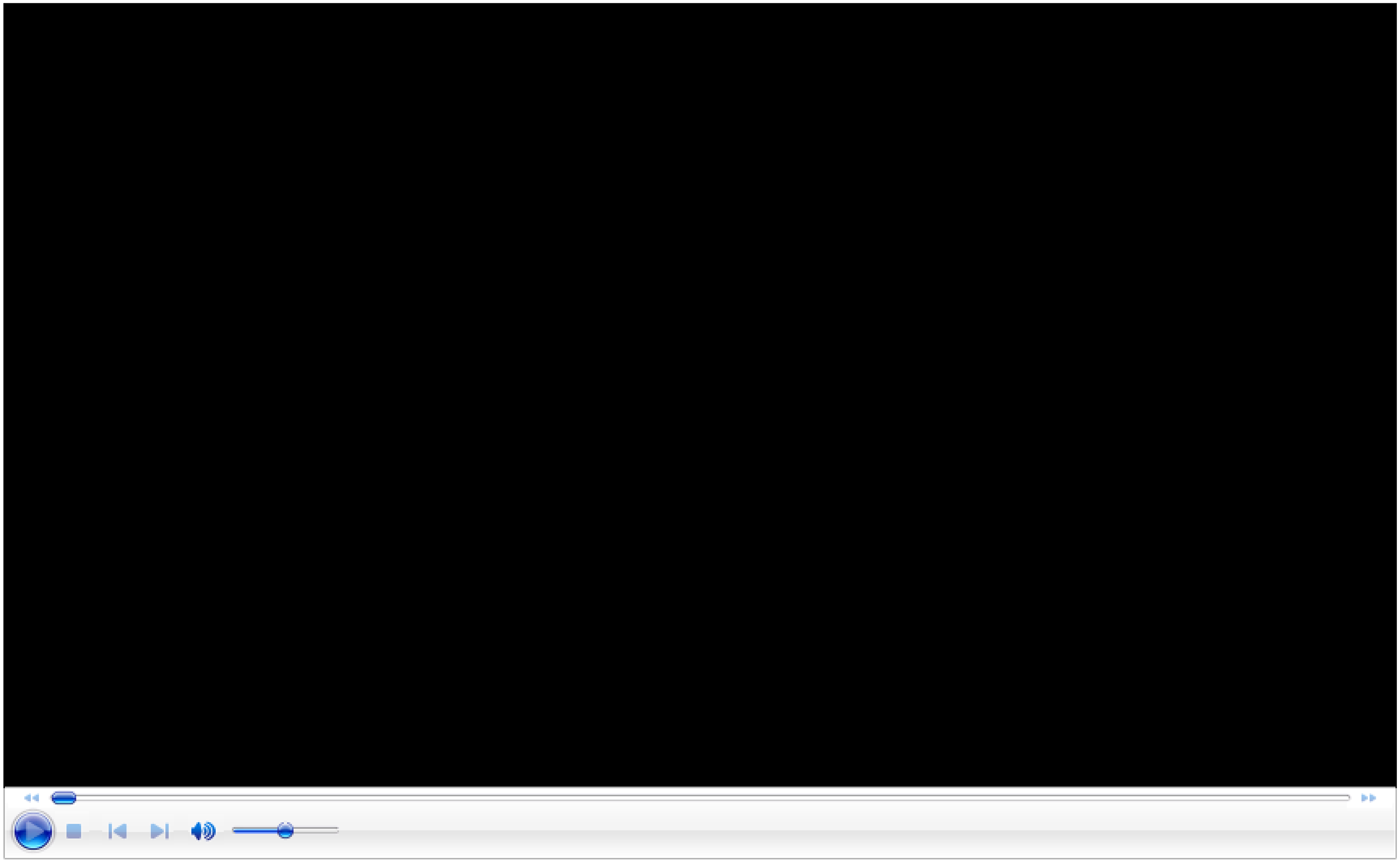
(a) Primary root of maize bending gravitropically (LMs)

(b) Statoliths settling to the lowest sides of root cap cells (LMs)

Mechanical Stimuli

- The term **thigmomorphogenesis** refers to changes in form that result from mechanical disturbance
- Rubbing stems of young plants a couple of times daily results in plants that are shorter than controls

- **Thigmotropism** is growth in response to touch
  - It occurs in vines and other climbing plants
  - The sensitive plant, *Mimosa pudica*, folds its leaflets and collapses in response to touch
    - Results from rapid loss of turgor in specialized motor cells
- Rapid leaf movements in response to mechanical stimulation are examples of transmission of electrical impulses called **action potentials**



Video: Mimosa Leaf

Figure 31.21

(a) Unstimulated state (leaflets spread apart)

(b) Stimulated state (leaflets folded)

Environmental Stresses

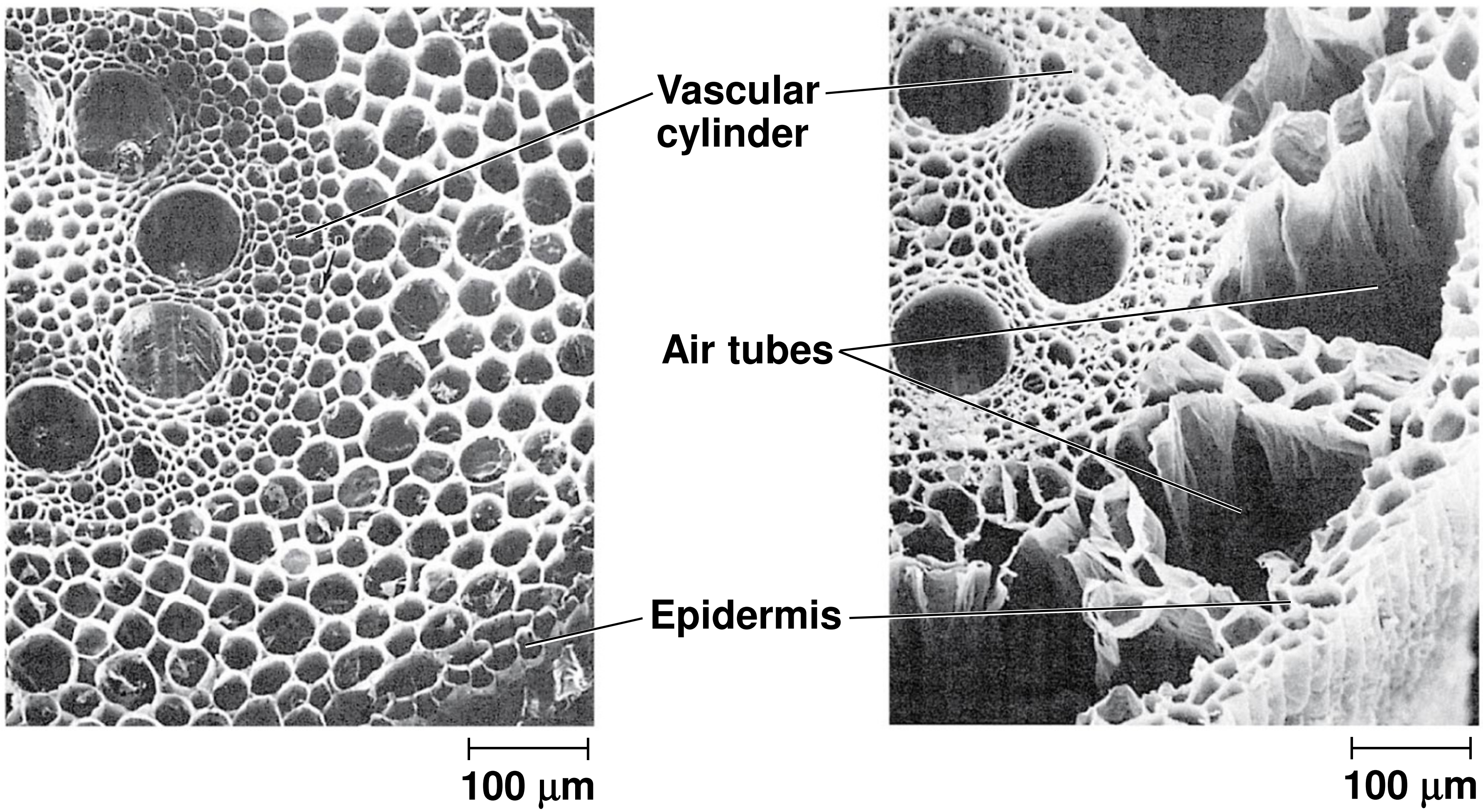
- Environmental stresses have a potentially adverse effect on survival, growth, and reproduction
- Stresses can be **abiotic** (nonliving) or **biotic** (living)
  - Abiotic stresses include drought, flooding, salt stress, heat stress, and cold stress
  - Biotic stresses include herbivores and pathogens

Drought and Flooding

- During drought, plants reduce transpiration by
  - Closing stomata
  - Reducing exposed surface area
  - Shedding their leaves

- Enzymatic destruction of root cortex cells creates air tubes that help plants survive oxygen deprivation during flooding
  - “Snorkels”

Figure 31.22



(a) Control root (aerated)

(b) Experimental root (nonaerated)

Salt Stress

- Salt can lower the water potential of the soil solution and reduce water uptake
- Plants respond to salt stress by producing solutes tolerated at high concentrations
  - Keeps the water potential of cells more negative than that of the soil solution
- *Halophytes* are salt-tolerant plants
  - Adaptations such as salt glands that pump salts out across leaf epidermis

Heat Stress

- Excessive heat can denature a plant’s enzymes
- Transpiration helps cool leaves by evaporative cooling
- **Heat-shock proteins** are produced at high temperatures
  - Help protect other proteins from heat stress

Cold Stress

- Cold temperatures decrease membrane fluidity
  - Altering lipid composition of membranes is a response to cold stress
- Freezing causes ice to form in a plant’s cell walls and intercellular spaces
  - This lowers the extracellular water potential
  - Water leaves the cells
  - Leads to toxic solute concentrations in the cytoplasm
- Many plants, as well as other organisms, have antifreeze proteins that prevent ice crystals from growing and damaging cells

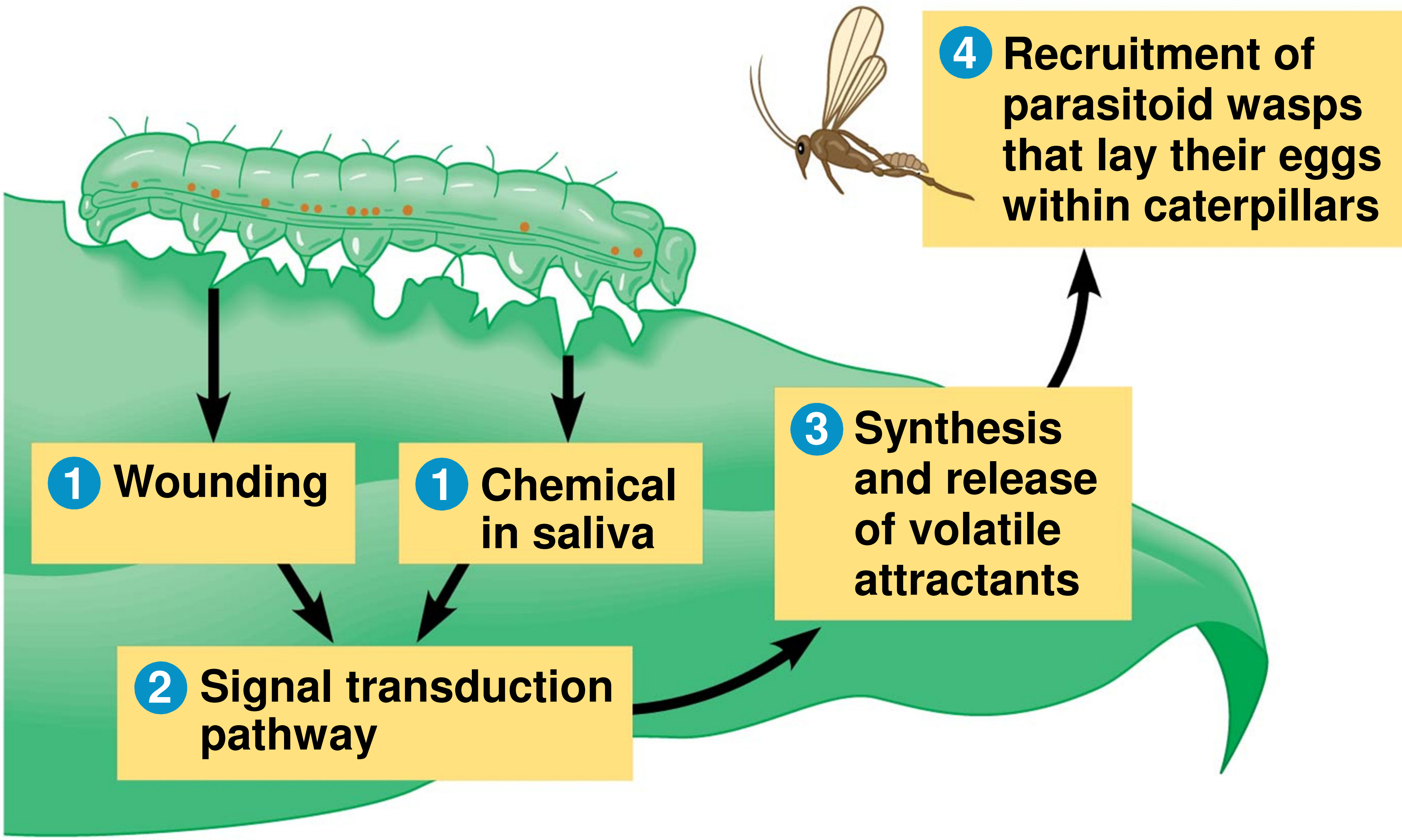
Concept 31.4: Plants respond to attacks by herbivores and pathogens

- Plant disease epidemics can lead to huge problems for people and the environment
  - Potato late blight caused Irish potato famine
  - Chestnut blight and sudden oak death altered communities
- Often the result of infected plants or timber being inadvertently transported around the world
- Through natural selection, plants have evolved defense systems to deter herbivory, prevent infection, and combat pathogens

Defenses Against Herbivores

- Herbivory, animals eating plants, is a stress that plants face in any ecosystem
- Plants counter excessive herbivory with
  - Physical defenses
    - Thorns and trichomes
  - Chemical defenses
    - Distasteful or toxic compounds
- Some plants even "recruit" predatory animals that help defend against specific herbivores
- Plants damaged by insects can release volatile chemicals to warn other plants of the same species

Figure 31.23



1 Wounding
1 Chemical in saliva
2 Signal transduction pathway
3 Synthesis and release of volatile attractants
4 Recruitment of parasitoid wasps that lay their eggs within caterpillars

Defenses Against Pathogens

- A plant's first line of defense against infection is the barrier presented by the epidermis and periderm
- If a pathogen penetrates the dermal tissue, the second line of defense is a chemical attack that kills the pathogen and prevents its spread
  - Enhanced by the plant's ability to recognize certain pathogens

Host-Pathogen Coevolution

- A **virulent** pathogen is one that a plant has little specific defense against
- An **avirulent** pathogen is one that may harm but does not kill the host plant

- **Gene-for-gene recognition** is a form of plant disease resistance that activates plant defenses
- These defenses include the hypersensitive response and systemic acquired resistance

The Hypersensitive Response

- The **hypersensitive response**
  - Causes localized cell and tissue death near the infection site
  - Induces production of proteins that attack the specific pathogen
  - Stimulates changes in the cell wall that confine the pathogen
- Localized and specific

Systemic Acquired Resistance

- **Systemic acquired resistance**
  - Causes plant-wide expression of defense genes
  - Protects against a diversity of pathogens
  - Provides a long-lasting response
- Nonspecific